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SPECIAL NOTICE.

For those desiring to join The Illuminating Engineering Society or subscribe to its official organ *(The Illuminating Engineer)* special attention is directed to the leaflet inserted at p. 210 in this issue.

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The ILLUMINATING ENGINEER

ELECTRICITY · ACETYLENE · OIL · GAS

Edited by LEON GASTER

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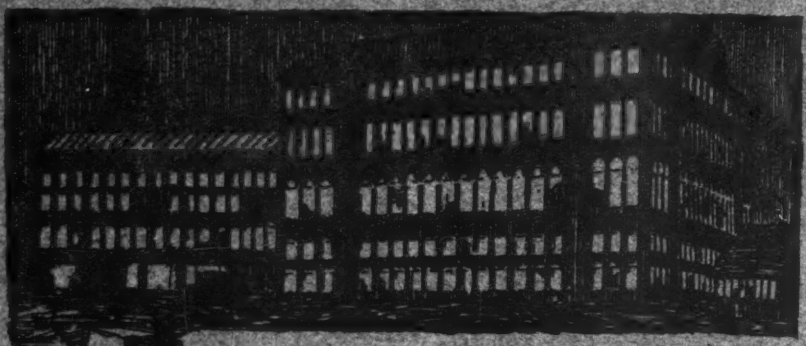
This issue contains the Paper entitled **"Intermittent Illumination in Industry,"** read by J. F. CROWLEY, D.Sc., B.A., M.I.E.E., at the Annual Meeting of The Illuminating Engineering Society on May 24th, 1923.

Other matters dealt with include :—

THE RELATION BETWEEN LIGHTING CONDITIONS AND STREET ACCIDENTS—THE NATIONAL GAS EXHIBITION—THE LIGHTING OF CINEMA THEATRES—NEW APPARATUS FOR DETERMINING MEAN SPHERICAL CANDLEPOWER, ETC.



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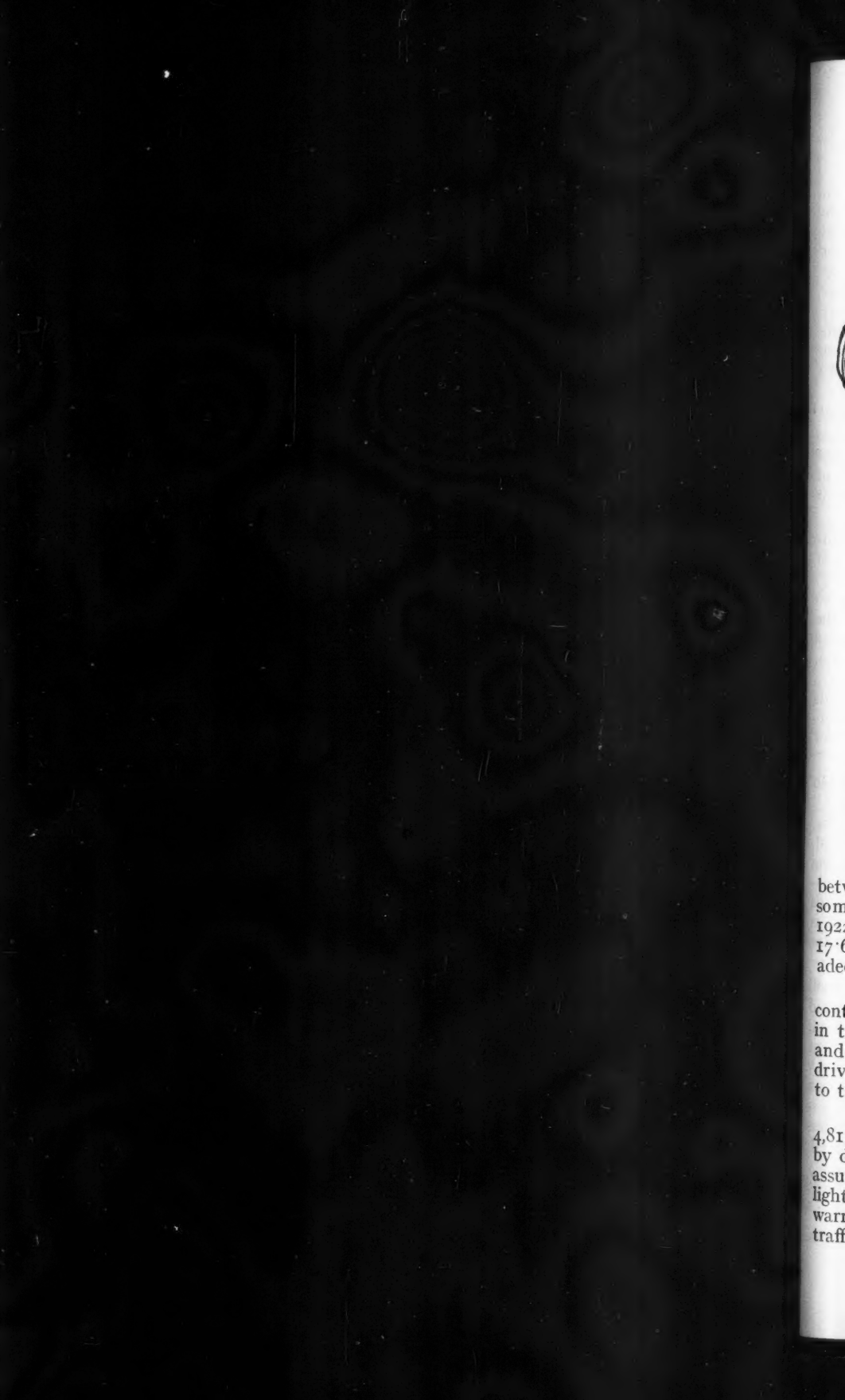

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EDITORIAL.

The Relation between Public Lighting and Street Safety.

We have frequently referred to the need of data showing the relation between public lighting and the safety of traffic. In 1918 the writer devised some tables to enable such data to be collected on a uniform basis. In 1922 it was estimated, as a result of data collected in 32 American cities, that 17·6 per cent. of fatal accidents due to automobiles were caused by inadequate lighting.

The Report of the Commissioner of Police for 1922, now available, contains an analysis of street accidents in some respects more complete than in the past. A distinction is drawn between accidents occurring before and after dark, and caused respectively by horse-driven and mechanically-driven vehicles. Accidents are also divided into three sections according to the age of the persons concerned.

The total number of persons injured by day was 20,736, and by night 4,811 (roughly 25 per cent.); the corresponding fatal accidents were 510 by day and 165 by night (about 32 per cent.). A casual observer might assume that, as the number of accidents is greater in the daytime, artificial lighting can have little influence. But this conclusion would be unwarranted. During the greater part of the night there is scarcely any traffic. It is only during the rush periods, when people are going to or from

their business, and at the late hour when crowds leave the theatres, etc., that there is any great liability to accidents. On the other hand, streets are continuously crowded during daylight hours. Moreover, of the total accidents recorded, about a third happened to children, *i.e.*, persons under the age of 15 years, and in certain districts the proportion was as high as two-thirds. It is evident that in general there will be a much smaller number of children in the streets by night than during the day. For these and other reasons it is inevitable that the actual number of accidents occurring by day should be greater than those at night. Indeed, taking these circumstances into account, the proportion of night accidents (32 per cent.) appears considerable.

In the case of slow-moving horse driven vehicles accidents by night form only a very small ratio to those by day. But motor-cab accidents by night form 70 per cent. of those by day. This is to be expected, as it is chiefly in the case of fast vehicles, travelling through a great variety of streets, some illuminated more brightly than others, that bad lighting is likely to have caused accidents.

An examination of the "Night to Day" ratios for 1913-22 yields interesting results. In 1913 it was 17 per cent., but during the war-period of 1914-16 it increased to 26 per cent., doubtless owing to the street darkening. During 1917-19 the ratio fell to 12 per cent. This might be due partly to the effect of air-raids in keeping people at home, but probably also to the better methods of street darkening introduced. In 1920-22 the ratio jumps up abruptly to 29-32 per cent. This has an obvious and curious explanation. For 1913-19 the day period was assumed to be from 6 a.m. to 9 p.m., irrespective of the seasonal variations in daylight. But from 1920 onwards the words "day" and "night" meant before and after dark, so that naturally many busy periods formerly included in the daylight period were now counted as occurring after dark.

Some very striking information on street accidents has also been collected by Mr. H. E. Blain, the Chairman of the London "Safety First" Council. Attention is drawn to the continuous increase in motor traffic. In 1913 there were 26,000 mechanical vehicles in Great Britain and Ireland. To-day there are a million. During 1922 the number of vehicles passing Hyde Park Corner between 8 a.m. and 8 p.m. attained about 56,000—roughly equivalent to an average of 80 a minute, and at certain busy periods of course considerably more. With traffic proceeding at this rate it is easy to see how readily accidents might be caused by inability to see persons or vehicles clearly in the case of inadequate lighting.

While the number of street accidents for the country as a whole still tends to increase, it is satisfactory to note that this increase is less rapid in London, where "safety first" methods have doubtless had a good effect. It would be helpful if facilities could be granted for the inspection of accident returns with a view to tracing the number occurring within certain busy hours at various times of the year. If power were granted by legislation to inquire into and report upon every fatal accident in the streets (as is already done on the railways), a systematic examination would doubtless enable many causes of accidents, including inadequate lighting, to be traced, and remedies suggested. Meantime the formation of the National "Safety First" Association, whose activities embrace the whole country, should lead to more reliable data being collected and concerted action being taken for remedial legislation.

The National Gas Exhibition.

In every industry the need for a periodical " taking stock " is recognised, and occasional exhibitions are most valuable, both as a means of educating the public and as an opportunity afforded those connected with the industry to review progress.

The National Gas Exhibition, which opened in Birmingham on September 17th, seems to have met both requirements very successfully. A special feature was the series of lectures and addresses, many of them delivered in accordance with the happy arrangement whereby the annual meeting of the British Commercial Gas Association was timed to coincide with the holding of the Exhibition. The chief note sounded in the addresses of the President (Alderman J. H. Lloyd) and Executive Chairman (Mr. F. W. Goodenough) was the aim of rendering service to the consumer, which carries with it special training and education of representatives in a knowledge of modern principles of illumination. Most of the lectures bore on some special application of gas, either in industry or public service. Dr. C. W. Saleeby, in dealing with " Light and Life," urged the need for action against the smoke nuisance which, by its limitation of sunlight, was responsible for abnormal conditions inimical to health. Dr. R. H. Jolly, Medical Officer of Health for Wolverhampton, spoke on the same subject. Capt. W. J. Liberty delivered an interesting lecture on " The Romance of Artificial Lighting." A judicious step was the enlistment of the help of medical men and other outside experts interested in the *use* of gas, as well as those concerned in its production and distribution—certainly one of the chief principles to be aimed at in successful propaganda work.

The exhibits appear to have covered a very wide range, practically all the leading firms being represented. A feature was the display of well-designed burners, and it is to be hoped that the public will soon learn to discriminate between the scientifically constructed article and the cheap but shoddy one, which is dear at any price. We were glad to note the growing tendency of manufacturers to pay attention to proper methods of shading. The recently introduced silica glassware has proved a boon in this respect, and pleasing forms of semi-indirect gas units, once regarded as exceptional and experimental devices, are now becoming quite widely used.

The recognition of the need for better educational facilities has been illustrated by the establishment of a studentship at the Imperial College of Science and Technology, which should, like Leeds University, become a centre for research on problems connected with the use of gas. We gladly note, both in the exhibits and in the lectures delivered, an appreciation of the fact that lighting still offers a very profitable field for gas, which should by no means be neglected. We understand that the Birmingham Gas Department, which was associated with a great deal of useful work in connection with the Exhibition, has shown exceptional enterprise in developing this branch of work and in educating consumers to appreciate the benefits of good illumination.

The use of Synchronously Intermittent Light in Industry.

The paper on the above subject read by Dr. J. F. Crowley at the annual meeting of the Illuminating Engineering Society on May 24th, deals with a new and fascinating field of study. The production of "stroboscopic" effects when moving objects are viewed by the light of an alternating current arc is familiar. But the light, while undergoing marked fluctuations, is not completely extinguished at the moment of reversal of current, whereas with the new neon lamps, the changes of current are followed instantaneously by the light. Hence with this source the effect is more marked, and is very suitable for experiments on moving objects.

Dr. Crowley gave many interesting demonstrations of the use of the principle. The idea of using rotating discs bearing various patterns, and illuminated by a neon lamp supplied with alternating current, to test the speed of motors is familiar. Observation of the changing appearance of the illuminated patterns offers a delicate means of adjusting the speed of alternating current machinery. Rotating mirrors have been applied in some instruments. One of the most striking of these, devsied by the British Research Association for the Woollen and Worsted Industries, enables the beam of an arc to sweep the whole line of spindles at such a frequency that each appears to be at rest. The Elverson Oscilloscope, utilising the intermittent light from a neon lamp, achieves the same object. On the occasion of his lecture Dr. Crowley applied this apparatus to the study of the motions of a sewing machine. The vertical driving rods could be caused to appear at rest, or moving very slowly, and the number marked on a small lever, actually in rapid vibration, could be read with ease.

These devices place a new weapon in the hands of the student of mechanics. Motions which are far too rapid to be discerned by steady light can be "slowed down" to such an extent as to be studied at leisure. Defective actions in machinery hitherto only revealed by spoiled work, can be actually witnessed by the operator, and the necessary adjustment in the machinery made. In the textile industries, where intricate high-speed machinery is used, and the consequences of faulty adjustment are serious, this method of study seems likely to prove of great utility; and it should also prove a valuable means of investigating many effects hitherto only treated theoretically, such as the whirling of shafts, the vibrations of unbalanced machinery, and the results of inaccurately fitting bearings.

Resting, as it does, on the phenomenon of "persistence of vision," the method bears a close resemblance to the kinematograph. But whereas the latter furnishes a record of high-speed motions, after they have taken place, the oscilloscope enables us to perceive them whilst they are occurring. The whole subject is a new one. But the results already secured are sufficient to show how much may be learned by the application of this novel apparatus.

LEON GASTER.

TRANSACTIONS

OF

The Illuminating Engineering Society.

(Founded in London, 1909.)

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INTERMITTENT ILLUMINATION IN INDUSTRY,

With Special Reference to its Use for the Examination of Moving Bodies.

By J. F. Crowley, D.Sc., B.A., M.I.E.E.

(Paper read before the Illuminating Engineering Society, at the Annual Meeting, held at the House of the Royal Society of Arts, 18, John Street, Adelphi, London, W.C., at 8.15 p.m., on Tuesday, May 24th, 1923.)

Introduction.

In his endeavour to prove that motion did not exist, Zeno, pupil and friend of Parmenides, was responsible for the following among other paradoxes:—"So long as anything is in one and the same space, it is at rest. Hence, an arrow is at rest during every moment of its flight, and therefore also during the whole of its flight." This conclusion is scarcely acceptable to philosophy to-day, but the modern physicist will recognise a connection between the statement that "an arrow is at rest during every moment of its flight," and the photographs by Boys twenty-five centuries later of bullets in flight, made by illuminating them for an instant by light from an electric spark. If a body is in motion and is illuminated for a sufficiently short period of time, it appears to the eye to be at rest, and during the instant of illumination it can be photographed in its apparent state of rest, provided its position in space can be predetermined, and that it can be illuminated with sufficient intensity for the light from it to affect a photographic plate. Direct photographic registration may not be possible, however, if the velocity of the body is excessive, or if there is difficulty in sufficiently illuminating it during the short exposure. If, on the other hand, the motion is periodic or recurrent, then a photographic plate can, by means of suitable devices, be exposed at successive instants while the body is passing through the same space interval in the same direction, and the additive effect of the successive momentary exposures can be made to give the result of a prolonged continuous exposure.

The impression of an image formed on the retina of the eye like the image on a sensitised plate is retained for a certain time after the object producing the image has been removed or cut off from view. After that time has elapsed, the image will be completely obliterated from the retina, whereas, an image once impressed on a sensitive plate may be regarded as permanent for practical purposes, if removed from the further action of light. The retention or persistence of visual impressions is known as "persistence of vision," and this phenomenon can be employed to enable the eye to secure, in a

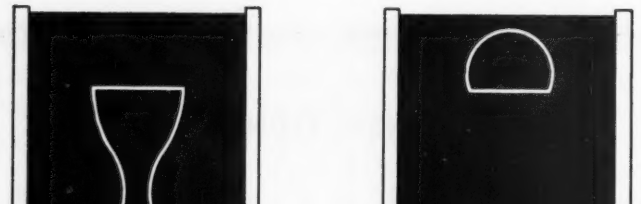


Fig. 1. Thaumatrope.

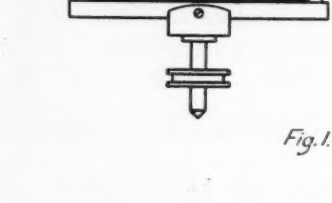


Fig. 2. Phenakistoscope.

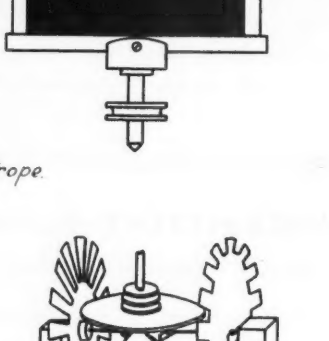


Fig. 3. Faraday's Instrument.

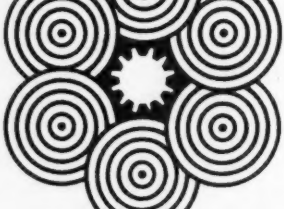


Fig. 4. Strobic Circles

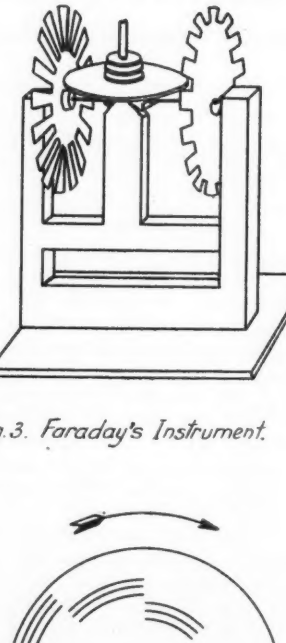


Fig. 5. Benham's Top.

manner somewhat analogous to that of the photographic plate, the effect of successive exposures to light from objects in true periodic or recurrent motion. It can, in other words, be used to produce the appearance of being at rest in objects which are rapidly moving if the eye is given successive periodic "glimpses" of short duration, of them. There is a second important application of the phenomenon also that deserves mention, viz., its employment for producing the appearance of motion from objects actually at rest as in the case of the kinematograph which produces this effect from a series of photographs on a film.

Instruments or apparatus that give the appearance of rest or of slow motion to bodies in rapid motion are termed "stroboscopes," and the first practical instrument of this type was introduced by Plateau of Ghent (1801-1883). Plateau cut equally spaced radial slits in a disc, arranged so as to revolve, and through these he viewed a vibrating tuning fork. If the number of "glimpses" of the vibrating fork be secured through the slits equalled or was a sub-multiple of the number of times the limb of the fork passed through the same space interval, the fork appeared to be at rest in a particular position.

Plateau also embodied his principle in the phenakistoscope (Fig. 2), a form of apparatus designed to produce the appearance of motion from bodies at rest and consisting of a disc with radial slits or holes arranged to revolve in front of a plane mirror. If pictures representing objects in successive stages of motion are fixed radially at the back of such a disc, and the image of these in the mirror is viewed through the slits, the illusion of motion will be produced. The thaumatrope (Fig. 1) devised by Paris preceded the phenakistoscope, and was another device of the same type. It consisted of a card capable of being revolved either vertically or horizontally, and having on one side, say, a cup and on the other a ball suitably placed, when by twirling the card so as to bring ball and cup into the field of vision in rapid succession, owing to persistence of vision, both objects were seen at once, the ball appearing to rest in the cup. In the first volume of the Royal Institution *Journal* will be found a paper by Faraday, which deals with stroboscopic effects, though he did not call them by that name, and in Fig. 3 an instrument made by him is illustrated. This device was arranged to revolve two toothed discs in opposite directions at variable relative speeds, and on viewing one wheel through the teeth of the other a creeping or stationary image could be obtained as desired. The zöetrope, or wheel of life, an old toy familiar to most children, was developed by Horner in the sixties, and gave similar results to the phenakistoscope, but without employing a mirror. This instrument consists of a cylinder capable of being revolved round a vertical axis, and having mounted on its interior photographs or sketches showing a body in successive stages of motion. The illusion of motion can be secured by looking at the moving pictures through a series of vertical slits in the walls of the revolving cylinder.

The devices described so far were adapted for direct observation only and could be used by one or, at most, two persons at once. The phenakistoscope was now adapted by Duboscq to the projection on to a screen of images which could be viewed by a number of people at the same time, and Plateau's revolving disc with slits was later employed by Rose in connection with an optical projection lantern in his photodrome. The photodrome threw an intermittent beam of light on to moving wheels, etc., and gave the appearance of bringing them to rest. Köenig carried the principle further by the introduction in 1873 of revolving mirrors, for viewing the manometric or vibrating flames he used for sound analysis, and Muybridge in 1877 studied the movements of animals, such as galloping horses, by taking a series of so-called "instantaneous" photographs at various stages of observed movements and viewing these in the zöetrope, or in the phenakistoscope.

The praxinoscope of Reynaud was introduced in 1877, and this forerunner of the kinematograph enabled silhouette figures in successive stages of motion to be projected on a screen in a "still life" setting. The zoo-praxinoscope was a variant of this. Professor Silvanus Thompson, a past president of this Society, introduced in 1877 an

illusion (Fig. 4) depending on persistence of vision which he termed "strobic circles"—circles so arranged that by giving the card on which they were mounted a slow rinsing movement they appeared to revolve. In 1870 McLeod and Clarke employed an apparatus consisting of a rotating black cylinder with white lines ruled on the black surface at right angles to the plane of rotation for the purpose of studying the vibrations of tuning forks. In 1882 Marey constructed a photographic camera fitted with a revolving disc with radial slits for taking photographs of moving objects, and carried out a number of experiments on the lines of Muybridge. The kineograph was introduced in 1886, and its successor, the mutoscope, in the early 'nineties. Both of these devices consisted of a series of pictures on thin paper bound as a book, by rapidly releasing the leaves of which the illusion of motion was secured. In the kinora system of home kinematography developed about 1900, a similar method was adopted for mounting the finished prints. Books of this type were merely a development of similar books which were on sale in the London streets some thirty years earlier.

Anschütz introduced an important improvement on the zöetrope which deserves mention in the light of subsequent developments, viz., the electrical tachyscope. This consisted of a wheel on which were mounted transparencies made from photographic negatives of moving bodies. As the wheel was revolved, the pictures passed in front of a box containing a vacuum tube, which was operated from a Rhumkorff coil, and flashed each time a picture appeared. The lamp thus threw the pictures into bold relief, and the illusion of motion was secured.

The kinetoscope of Edison, first constructed as a laboratory instrument in 1890 and publicly exhibited in 1893, consisted of a celluloid film 40 ft. long containing pictures of bodies in motion arranged to pass continuously in front of a small electric lamp and behind a magnifying lens through which the film could be viewed. The apparatus was of the "observation" type and between the eye and the lens was placed a revolving disc, with a radial slit near the periphery, which made one revolution in the interval between the appearance of each picture. The film and the disc were operated by a small electric motor and to prevent the slit and the film from getting out of synchronism the film had four perforations per picture at each side, which engaged with sprocket wheels.

The theatrograph or the animatograph, as it came later to be called, was built by Paul in 1895 and first exhibited publicly in 1896. It was a "projection" apparatus based on the kinetoscope, and consisted of a celluloid film as in the case of that instrument, and a special arrangement for moving each picture forward in jerks instead of continuously, so as to give a short period of "dwell" before the picture was changed. The kinematograph, generally on similar lines to the animatograph but differing in mechanical details, was developed at the same time and independently, by Lumiere in France. The kinematograph, as instruments of this type are now universally called, forms a distinct application of the phenomenon of "persistence of vision." Its development is closely associated with that of photography and of the celluloid sensitive film, and need not be further considered here.

Before considering more closely the apparatus that have been evolved on the principle of the stroboscope, and their application to industry, it may be well to consider briefly the physiological principles on which they are based.

Physiological Considerations.

A certain minimum quantity of light must reach the retina before any object can be perceived. The light at this stage is of a neutral greyish appearance, and no colours can be distinguished. As the light is increased a point is reached at which the greyish light begins to resolve itself into the blues and greens of the object viewed. The reds then begin to emerge from the surrounding blackness, and at the same time the true recognition of brightness begins. A series of lights which to the eye appear to increase in equal increments of brightness would, if measured photometrically, be found actually to increase in geometrical progression. In other words, if the apparent

brightness be plotted against the logarithm of the intensity of illumination, we obtain for normal illuminations a straight line which becomes discontinuous at very low illuminations corresponding to colourless vision and again bends over at very high illuminations when dazzle prevents a true appreciation of brightness value.

If the period of illumination is very brief a somewhat stronger light is necessary for perception than if the light is continuous. The light required under these conditions has been determined by Blondell and Rey, and is given by the formula $(E-Eo)t=aE_o$ where E is the illuminating power necessary for visibility, Eo the minimum continuous illuminating power necessary for visibility, t the time of the brief illumination, and a the constant whose mean value is 0·21.

When a light impulse reaches the eye there is an appreciable time lag before the stimulus reaches the brain, and in like manner when a light impulse ceases the image remains for a considerable time. When the light impulse lasts for a very brief period, as, for instance, when an object is illuminated by a flash of lightning, the object does not commence to be perceived until after the light impulse has ceased, but the impression on the brain then lasts for something of the order of a tenth of a second before dying away completely. No reliable figures are available for the actual length of time intervening between the reception of the light impulse and its perception. The only figures, and these approximate, that are available, are for the actual duration of perception of brief illumination.

If an object is illuminated by a succession of flashes, the illumination is seen to flicker when the periodicity of the flashes is low. As the flash frequency is increased the flickering is reduced and disappears when the impression has not time to fall off perceptibly in intensity during the dark period between flashes. This frequency is commonly termed the "critical frequency" and varies with the ratio of the period of illumination to the period of darkness, with the intensity of the light, with its colour, and to some extent with the individual.

Ives, in the course of a series of experiments carried out with a view to studying the theory of the flicker photometer, made a series of measurements of critical frequency and found that on plotting the latter against the logarithm of the illumination intensity, the curve for white light was a straight line, the slope of which at a low illumination suddenly altered. When separate spectrum colours were plotted in the same way, a set of curves such as those shown in Fig. 8 was obtained. It will be noticed that the curve for red is straight throughout, whereas the curve for blue becomes horizontal at low illuminations. It will also be noticed that red requires a higher critical frequency for the disappearance of flicker than blue light, and that the curves for the other colours of the spectrum are intermediate between those for red and blue.

Ives assumed that an intermittent stimulus was received by the brain as a very much damped impression, and compared it with the flow of heat, and by applying the equations for heat he was able to arrive at calculated results which were a close approximation to the experimental results.

From this it would follow that a high critical frequency would correspond to a relatively quick perception as well as to a short persistence. Red light would, therefore, be perceived more quickly than blue. In order to prove this experimentally, he constructed an apparatus consisting of a disc and outer concentric ring capable of adjustment relatively to each other, and each provided with a slit approximately 5° in width and the whole arranged to revolve at a speed of one revolution per second, or less, by means of a motor. He inserted blue glass in the outer slit, and red glass in the inner, the two slits being set in line while the apparatus was stationary, and he illuminated both slits from the back, the apparatus being so protected that the front was in darkness except for the light through the slits. On rotating the disc the blue slit appears to be displaced and to lag behind the red, as his theory had led him to expect. Similarly, if the outer slit is dimly and the inner slit brightly illuminated by the same coloured light, the dimly illuminated slit appears to lag, showing that the bright light was perceived earlier than the dim light. In

Fig. 6. Bidwell's Disc.

Fig. 7. Ives' Disc.

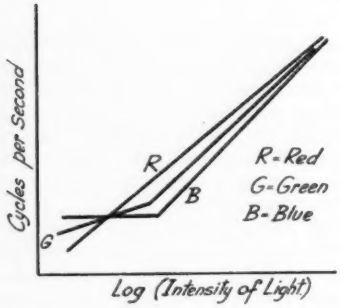


Fig. 8. Ives' Curves for various Spectrum Colours (not to scale)

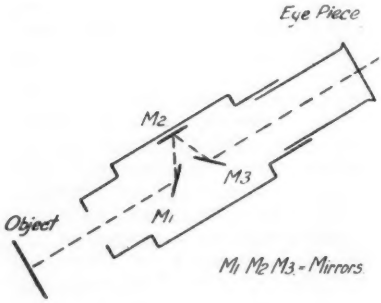


Fig 9. Dr Rayner's Apparatus.

Fig. 10. Diagram shewing positions at which light may be interrupted

Fig. 7 a diagram is shown to illustrate this effect.

The curves shown in Fig. 8 show clearly the difference in the critical frequency for different colours, and also the effect of different intensities of light on the frequency required for the disappearance of flicker, but as Ives' experiments were carried out with the use of an artificial pupil and other conditions which do not allow his figures to be reduced to simple units, his curves can only be taken as diagrammatic.

The kinematograph projector ordinarily projects 16 photographs per second on to the screen, and as this frequency is much below that required for disappearance of flicker, the early moving pictures on this account were very disagreeable and trying to the eye. Later, two further obscuring sectors were introduced in the shutter, in addition to the one required for shutting off the light whilst the picture was being changed, so as to increase the rate of intermittent illumination to 48 per second, and by this means the flickering was very much reduced. The film is moved to bring a new photograph on the screen in about 1-80th of a second, and then remains stationary for about 1-20th of a second. Owing, however, to the fact that the shutter does not obscure the whole picture instantaneously, it is necessary to make the sector which cuts off the light while the film is being moved, about 90° in width, and as too much light would be cut off if the two additional sectors were also of 90° they are in practice reduced to 43° in width. Owing to this inequality the full advantage of a frequency of 48 interruptions per second is not obtained, although there is a great improvement as compared with 16 per second. Some curves, which are taken from the "Dictionary of Applied Physics" by permission of the publishers, are reproduced in Fig. 20. They were taken on a screen illuminated by a kinematograph projector from which the film had been removed, and show the dependence of flicker on the frequency and on the intensity of the light. A diagram of the shutter is also shown on this figure.

When viewing an object by a stroboscopic beam, there will be no noticeable flickering at flash frequencies which are still low enough for the light if viewed direct to be seen to flicker greatly. This is due to the fact that the intensity of the light as reflected from the object is much less than that of the source itself, and for the same reason the frequency required for no flicker in stroboscopic work depends greatly on the nature of the object viewed, and while a frequency of 25 per second would be sufficient for a dark object, a bright object with bright illumination might require a frequency of 40 per second for no flicker to be perceptible. In practice the periodicity of the moving object is very often not great enough to make possible a flash frequency sufficient for the avoidance of flicker, and except where continuous observation is necessary a considerable amount of flicker is permissible. Sufficiently good stroboscopic work can be done on rotating machinery running at, say, 900 revolutions per minute corresponding to a flash frequency of 15 per second, and a stroboscope has been used at as low a speed as 300 revolutions per minute, although in the latter case there can be no question of a continuous image. It does not seem probable that any device for increasing the flash frequency analogous to the extra sectors of the kinematograph shutter will be found for stroboscopic work. It is possible, however, that in very special cases intermediate flashes illuminating a plain ground of the average colour and brightness of the object might be used, but if there were various distinct colours in the object, such a device would change the colour values if it did not alter the colours entirely, as in the experiments mentioned below.

Where the frequency of interruption of intermittent illumination is greater than the critical frequency, the average intensity of the intermittent light bears the same ratio to its instantaneous value that the time of exposure does to the total time. This is known as Talbot's law, and it has been confirmed by Hyde by experiments with a revolving sector shutter for all openings down to 10°, *i.e.*, for a ratio of time of illumination to total time of 1 to 36. This law is relied on when it is desired to vary the degree of illumination for experimental purposes without altering the composition of the light.

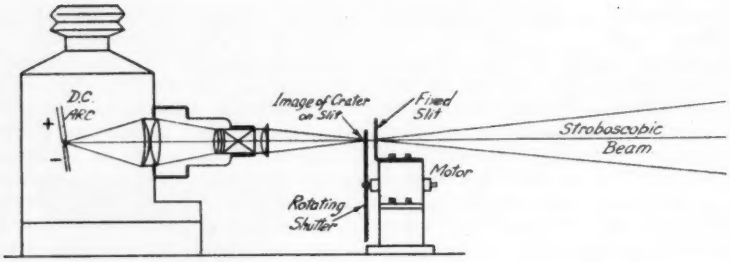


Fig. 11. Lantern Arranged for projecting Stroboscopic Beam

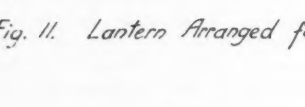


Fig. 12. Tuning Fork for edge vision
Frequency of opening = Fork frequency.

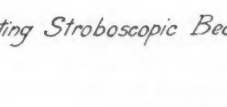


Fig. 13. Tuning Fork for Slit vision
Frequency of opening = 2× Fork frequency.

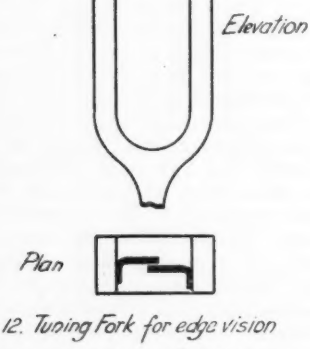


Fig. 14. Drysdale's Standard
Disc for Stroboscopic Measurements.

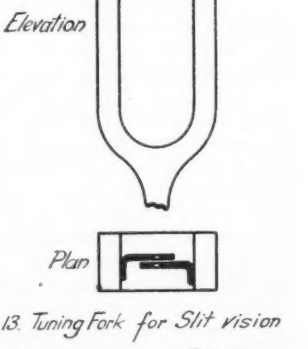


Fig. 15. Disc used by Robertson.

From what has already been said of Ives' experiments showing the different behaviour of the eye in respect of different colours, it might be expected that curious colour effects would occur with intermittent illumination. Some such effects have been noticed in stroboscopic work at different times, and, therefore, an account of one or two further experiments illustrating abnormal colour effects with intermittent illumination will not be out of place.

A toy, which was known as "Benham's top," was sold some years ago. This consisted of a disc as illustrated in Fig. 5, half of which was black while the other half had short arcs of circles drawn with thin lines on the white surface. When this disc is rotated in a clockwise direction at a particular speed the inner arcs appear red and the outer arcs blue, the intermediate arcs being of intermediate colours. If the direction of rotation is reversed, the outer arcs become red and the inner ones blue. These phenomena were investigated by Bidwell at some considerable length. He constructed various arrangements in some of which a black line surrounded by a white surface when suddenly illuminated appeared so distinctly red that it was impossible to distinguish it from a red line under the same circumstances. When a larger black surface was used, only the borders appeared red and the red appeared inside the borders of the black surface. In another experiment, in which a disc of translucent paper was illuminated by a lamp from behind, when one portion was suddenly obscured by a black shutter a blue edge appeared, in this case on the illuminated portion. The appearance of red at the rear edge of the black sector in a disc such as that used for stroboscopic work by Drysdale or Robertson (Figs. 14 and 15) will often be noticed, but the corresponding appearance of blue is not so easily perceived. The effects were put down by Bidwell to sympathetic excitation or reaction of the nerve fibres in the immediate neighbourhood of the point where the sudden change of illumination was produced, the nerve fibres which were sensitive to red being more affected in each case than those sensitive to blue and green.

If, after looking attentively at some bright colour for a few moments, the eyes are turned to look on a white screen, an image of the same shape but of complementary colour to that of the original object, will appear on the white surface. Or again, if a brightly illuminated colour is surrounded by a white frame, the frame will, after a short time, appear to be of the complementary colour. These effects are considered to be due to fatigue of the eye in respect of one colour producing greater relative sensitiveness in regard to others. This effect can, however, be observed with rapidly intermittent illumination where the light is very bright, and in such a way as to completely destroy the original colours, leaving only the complementary colours visible. One instance of this is noticeable with Benham's top, where the sectors previously described as appearing red or blue would appear of the complementary colours if the top were spun in direct sunlight. Bidwell constructed a disc in which this effect was shown in a much more striking manner. This disc, which is illustrated diagrammatically in Fig. 6, was about 8 in. in diameter, and one half was covered with black velvet while the other half was white, with the exception of a sector of 45° which was cut out of the white half adjoining the black. When the disc was rotated at from six to eight revolutions per second, so that the open sector followed the black, and a coloured picture was placed behind the disc in such a way that it could be seen intermittently through the open sector, the picture appeared of the complementary colours of the original; thus a picture of a red rose with green leaves was seen as a green rose with reddish leaves. Although this is strictly an intermittent illumination effect it is improbable that it will arise in stroboscopic work.

Turning now to the consideration of securing photographic registration of the results obtained with stroboscopic devices, Curve A, Fig. 21, shows a plate characteristic curve obtained by plotting the density of a negative against Log. E where E is the product of the intensity of the light and the time of exposure. It will be seen that this curve is practically a straight line over its central portion, but bends over in the regions of over and under exposure. In this

Fig. 16 Characteristic curve of Neon Lamp

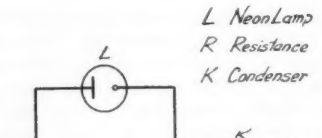


Fig. 17. Diagram of Connections for Automatic flashing Neon Lamp

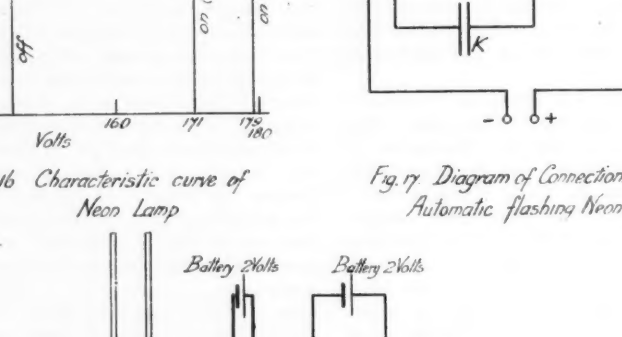
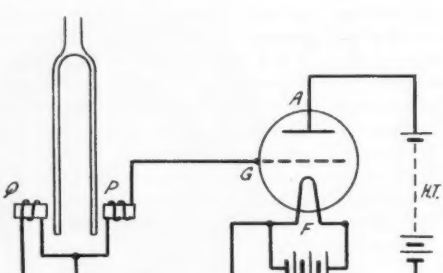


Fig. 18. Connections of Tinsley Tuning fork Stroboscope.



A - Anode of Valve
G - Grid of Valve
F - Filament of Valve
P - Coil connected in grid circuit, wound on one pole piece of auxiliary magnet
Q - Coil connected in grid circuit on other pole piece of Auxiliary Magnet.

Fig. 19. Diagram of Connections of circuit for maintaining oscillations of Tuning fork by means of Triode Valve.

respect it is very similar to the characteristic of the eye. The bending of the curve in the region of over-exposure corresponds to dazzle conditions, and in the region of under-exposure to the abnormal conditions of colourless vision with very low illumination. As the density of a photographic plate is within wide limits proportional to the photo-chemical action, this similarity has given rise to the photo-chemical theory of vision.

Since the density of a photographic plate is proportional to Log. E, and since, likewise, the physiological measure of brightness is proportional to the logarithm of the illumination intensity, it follows that the gradation of light and shade on a photographic plate will correctly reproduce the gradations of an object as seen by the eye, provided that the plate is correctly exposed. If, however, the plate is much over or under exposed so that the curved portion of the plate characteristic is utilised, the gradations are quite different to what is required. As might be judged to be the case from the shape of the curve where very short exposures are necessary, the plate is rendered more sensitive by first being evenly exposed all over to a sufficient extent to bring the density up to the commencement of the straight portion of the curve. The short exposure to the object after this produces a much greater increase of density for a given exposure than would be the case if the plate was previously unexposed, besides giving the correct gradations of light and shade.

Abney was the first to point out that the total exposure with intermittent illumination did not produce the same density as the corresponding continuous exposure. Curve B, Fig. 21, shows the characteristic for a plate exposed intermittently. The exact shape of B and the relative exposures required for continuous and intermittent illumination vary according to the particular type of plate used, and also according to the ratio of exposure to rest. In some cases in Abney's experiments about 60 per cent. longer exposure was required with intermittent illumination to produce the same density as with continuous illumination.

From experiments made by Nutting it would appear that, as was shown to be the case with the retina, there is a certain minimum light intensity below which no image can be obtained on a photographic plate, no matter how long the exposure, but according to his experiments a much fainter source of light, provided it has fairly large apparent dimensions, can be detected by the colourless vision of the eye than would suffice to produce an image on a photographic plate.

Differences in sensitiveness of photographic plates with regard to different colours are well recognised so far as continuous illumination is concerned, and as their behaviour in this respect appears to be the same with intermittent illumination it will not be necessary to go further into this matter here.

Stroboscopic Apparatus.

Since a stroboscope is required to produce a distinct image of the object viewed, the individual glimpses given by it must be very short, and their shortness is only limited by the available intensity of illumination. With the kinematograph, on the other hand, a comparatively long exposure for each individual photograph is necessary so that the images of the rapidly moving objects shall *not* be sharp, as otherwise, to take an example, a man moving his right arm rapidly would appear to have two right arms in different positions, and the illusion of motion would be completely destroyed. This effect was noticeable with some of the early kinematographs, and it also accounts for the jerky motion observed with instruments such as the zöetrope, where *sharp* pictures are employed.

The eye sees an object by means of light reflected from that object, and consequently there are four possible ways in which the necessary interruption of vision for stroboscopic observations can be brought about, namely :—

(*a*) by an interruption of the light between the object and the eye ;

(*b*) by an interruption of light at the object ;

(*c*) by an interruption between the illuminant and the object ;

(*d*) by an interruption of the light itself.

(*a*) and (*c*) Fig. 10 involve the mechanical operation of some form of shutter at the

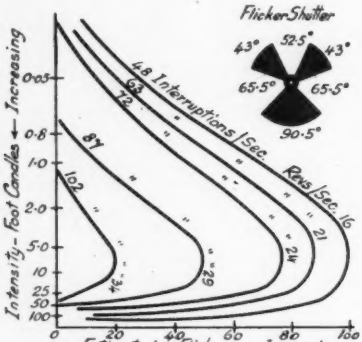


Fig. 20. Curves illustrating dependence of Flicker on frequency of Interruption and on intensity of Light. (From "Dictionary of Applied Physics" by permission of Macmillan & Co.)

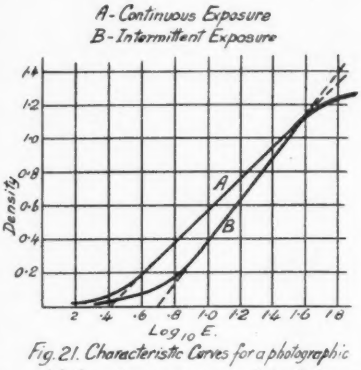


Fig. 21. Characteristic Curves for a photographic plate for continuous exposure and intermittent exposure. (From "Photography as a Scientific Implement" by permission of Messrs Blackie & Son, Ltd.)

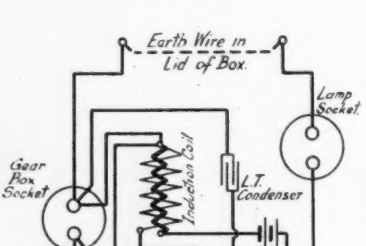


Fig. 22. Diagram of Connections of Elverson Oscilloscope.

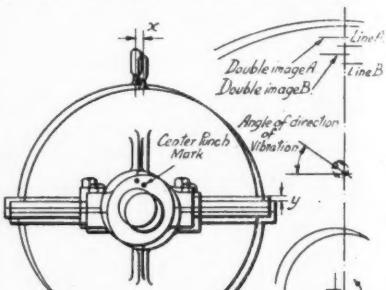


Fig. 23. Diagram illustrating "Double Image" Appearance of a Gear Case which is subjected to considerable vibration.

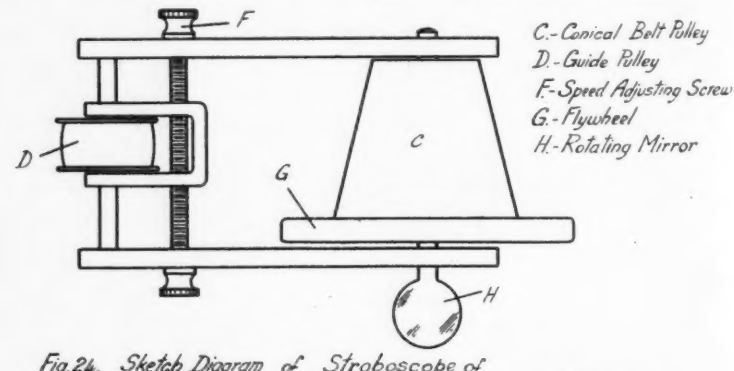


Fig. 24. Sketch Diagram of Stroboscope of British research Association for the Woollen and Worsted Industries.

correct intervals, such as, for instance, a rotating Plateau disc with a radial slit driven by a motor or other means, so that the slit periodically comes into the line of vision or allows the light to fall on the object. Vibrating or rotating mirrors might also be introduced to interrupt the illumination, and these have particular advantages in certain cases.

For case (*d*), where the source of light itself is interrupted, a metal filament lamp on an alternating current circuit was used by Hospitalier for synchronising the small motor of his instrument. A disc with alternate black and white sections was placed on the motor-shaft, and the fluctuations of light on a 50-cycle circuit were sufficient to make these sections appear stationary when the motor was turning at synchronous speed. An arc lamp fed by alternating current has also been used in a similar way, but neither of these methods gives sufficiently sharp and distinct alternations of light and dark for experimental investigation. The discharge of a Leyden Jar gives a brilliant light of very short duration and has been used for the photographing of rifle bullets in flight. The apparatus is, however, cumbersome, and scarcely practicable for other than laboratory use, and it was not till the recent introduction of the neon lamp that the method of interrupting the light itself took a definitely practical form.

The neon lamp was introduced in 1911, and consists of a bulb from which the air has been exhausted and into which a small quantity of neon gas has been admitted. The current passes by discharge between two electrodes within the bulb, and consequently, as the heat capacity of the rarefied gas is practically negligible, it lights up and darkens to all intents and purposes instantaneously as the current is switched on and off. It is stated that as many as 10,000 distinct flashes per second can be obtained. The lamp is highly efficient, taking about ½-watt per candle power, and it has a life of about 1,000 hours. As it cannot be made for very low voltages, an induction coil is employed when it is intended to use the lamp with accumulators of, say, 4 to 6 volts.

A higher voltage is required to light the lamp than would suffice to keep it glowing, *e.g.*, in a particular case 179 volts were required to start the lamp, which then continued glowing, until the voltage was reduced to 147 volts. Use was made of this fact by Pearson and Anson to produce automatic flashing by connecting a condenser in parallel with the lamp and a resistance in series, as in Fig. 17, and the flash frequency can be adjusted by the variation of either. Unless, however, the condenser is very large, the duration of each flash is so short as to give insufficient illumination for practical purposes.

Method (*b*), namely, the interruption of the light at the object itself, is exemplified in the device already referred to of McLeod and Clark, who used a cylindrical drum rotating about a vertical axis and covered on its curved surface with black paper, ruled with white lines parallel with the axis and about an inch apart. A horizontal beam of light was projected on to this drum, and moved up and down under the influence of sound waves. When rotating at the correct speed, a white curve is seen representing the form of the sound wave. This application is exemplified to-day in the visual arrangement of the Low Hilger Audiometer designed by Messrs. Twyman and Dowell, and made by Messrs. Adam Hilger. Here the black parts of the drum are used to intercept the light to the eye which the white parts reflect. The optical system of this instrument is shown in Fig. 25.

One of the early applications of the Plateau revolving disc was to the measurement of the speed of small motors, to which ordinary methods of speed counting could not be applied owing to the effect that such would have on the operation of the machines. A disc with suitable markings is placed on the shaft of the motor, whose speed has to be measured, and this is illuminated by light rendered intermittent by the interposition of a slotted disc. From the speed at which the disc has to be run in order to make the marked disc appear stationary, the required motor speed can be obtained. Fig. 11 shows a lantern and slotted disc arranged for projecting a stroboscopic beam as above described. Similar results can be obtained by observing the marked disc through the slits of the Plateau disc

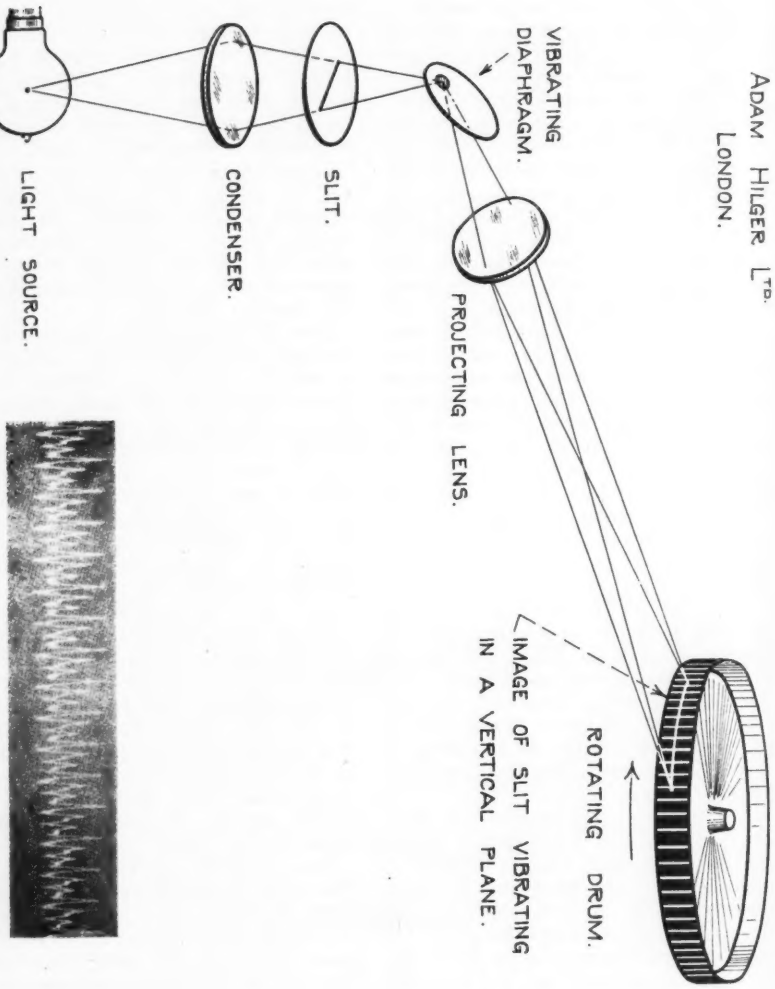


Fig. 25. Diagram of the optical system of the Low Hilger Audvmeter.

Typical sound curve as seen on the rotating drum.

instead of by the interruptions of projected light. A convenient method of measuring the slip of induction motors is mentioned by Belini, and consists in fitting the slotted disc on the motor shaft and observing the filament of a metal filament lamp fed from the same alternating current supply as the motor. If a permanent magnet is placed near the filament, the latter will vibrate in synchronism with the supply, but viewed through the slotted disc the apparent rate of vibration which is a measure of the slip of the motor, can be determined by counting.

Drysdale introduced the use of a tuning fork of known frequency with shutters attached to the limbs in place of the rotating slotted disc and employed a more elaborate disc with geometrical patterns of various shapes for the motor shaft, so that different patterns appeared stationary at different motor speeds, and thus was able to measure various speeds in steps, for taking running down curves or for calibrating tachometers. In Figs

12 and 13 two methods of arranging the shutters are shown, in the first of which the opening occurs when the limbs of the fork are expanded and the frequency of opening equals the fork frequency, while in the second the slit opening occurs when the fork is in the stationary position and twice the fork frequency is obtained. The design of the disc for the motor shaft which Drysdale used and which is still employed in conjunction with Messrs. Tinsley's instruments is shown in Fig. 14, and in Fig. 15 is an alternative design which was employed by Robertson.

The tuning fork is a very reliable instrument for the accurate measurement of time, since temperature changes produce a variation in frequency of only about 1 in 16,000 per degree Fahrenheit. The vibrations of the tuning fork can be conveniently maintained electrically either by a make and break as in Fig. 18, or by the use of a thermionic valve and a magnetised fork as in Fig. 19, and when this is done it makes a compact and practical instrument, especially for such purposes as the calibration of tachometers. In the most recent model supplied by Messrs. Tinsley & Co., the electrical connections of which are shown in Fig. 18, the shutters have been done away with, and the tuning fork is used to make the contacts of a neon lamp, by the light of which the Drysdale disc is observed. The tuning fork arrangement above mentioned measures speed in steps of about 50 revs. per minute over a range from 50 r.p.m. to, say, 3,000 r.p.m., with a tuning fork giving 50 periods per second. In order to get a stroboscopic beam of adjustable frequency, Drysdale devised an arrangement in which a small motor, whose speed was directly controlled by a tuning fork, drives a conical drum from which a disc is driven by friction, the speed of the disc depending on its position on the conical drum. The position of the disc is indicated by a pointer, which moves on a fixed scale and enables the flash frequency to be read off directly. The original instrument had a disc provided with radial slits for observation purposes, but the modern instrument employs a neon lamp, the contacts for which are made by the revolving disc. Drysdale also designed a slip stroboscope employing a conical roller and Plateau disc arrangement similar to that previously described but driven by a synchronous motor. A Drysdale disc was employed with this instrument, and the number of poles of the test motor was determined from the particular geometrical pattern on the disc that appeared stationary, the percentage slip being read off on the scale of the instrument. Both instruments are made by Messrs. Tinsley, and the former is illustrated in Fig. 26.

Kennelly and Whiting made a tuning fork with shutters like Drysdale's, but with movable jockey weights on the limbs of the fork, so as to obtain an adjustable frequency. A scale on the limbs of the fork gave the frequency of vibration for any position of the jockey weights.

Occasional use has been made of rotating or vibrating mirrors for stroboscopic work, and as they have been applied recently in industrial work with success, some mention should be made of them. Köenig for the study of sound waves employed a sensitive flame, which was caused to vibrate under the influence of a sound wave, and by rotating plane mirrors mounted on a vertical axis in front of it the variation in size of the flame was rendered visible. When the mirrors are rotated fast enough the images are shown as a band of flame extending right across the mirrors. By this method, the fundamental frequencies and harmonics of sound waves were studied. Another application of mirrors which may be mentioned is their employment by Duddell in connection with his oscillograph. The oscillograph itself is, in principle, a mirror-galvanometer of very high natural frequency, which is capable of following the instantaneous values of the current or voltage of an alternating current supply, and which gives a deflection proportional to the current or voltage. If the moving spot of light from the oscillograph were thrown direct on to a screen nothing would be seen but a line of white light, but when reflected by a rotating or vibrating mirror driven by a synchronous motor, the image on the screen appears as a continuous white curve of which the ordinates represent the instantaneous value of the current or voltage plotted against time as abscissa. If the conditions are steady

Fig. 26. Tinsley Strobometer.

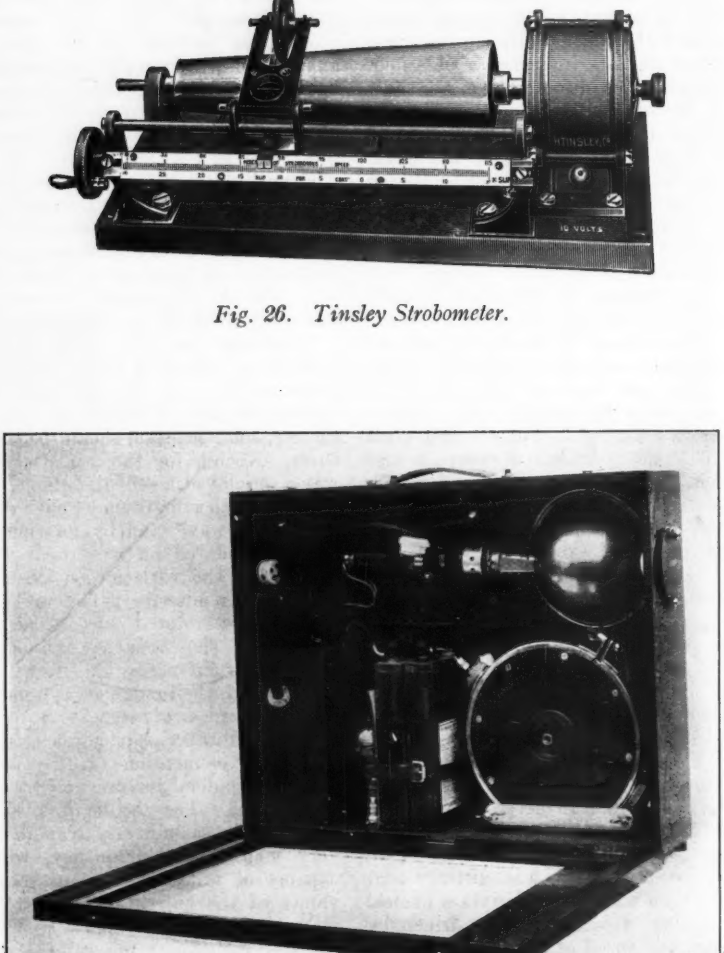


Fig. 27. Oscilloscope in portable case showing gearbox, lampholder, accumulators and induction coil.

so that each cycle of the alternating current truly repeats the previous one, the curve, as seen, becomes as steady as if permanently marked on the screen.

The British Research Association for the Woollen and Worsted Industries has recently devised an instrument, which is now being manufactured and which employs a rotating mirror. The instrument, of which a diagram is shown in Fig. 24, was designed for the investigation of the behaviour of yarn in spinning machines, but was also used to investigate the variation in the speed of the spindles. In this instrument the mirror H is driven by a flat cotton tape of the type used for spindle drives, which passes over a conical pulley C so that the speed of the mirror can be varied, the adjustment of the position of the tape on the cone being carried out by the thumb-screw F, which raises or lowers a guide-pulley D. The mirror is double-sided and made of silver or stainless steel. The beam of light from an arc is deflected by the mirror so as to sweep the whole line of spindles with intermittent light. The spindles can be made to appear stationary or as if moving slowly, and any defect in the winding of the yarn can be immediately detected.

A piece of apparatus which, though not based on "persistence of vision," is applicable to the solution of some problems similar to those discussed, was recently designed by Dr. Rayner, and is illustrated in Fig. 9. It consists of a cylinder capable of being revolved on its axis and fitted with three mirrors, M3, M2, and M1, arranged as shown so that the light reflected from a body in motion can be reflected from thence to the eye. If this mirror system is revolved at half the speed of an object under observation, such as a rotating wheel, the wheel will appear at rest. It follows also that stationary objects viewed will appear to revolve at twice the speed of the optical system.

A standard stroboscopic instrument designed to be readily applicable to any industrial machine and suitable for any class of stroboscopic work has recently been put on the market by Messrs. Herbert Kennedy & Co., Ltd., under the name of the oscilloscope. This instrument consists essentially of a neon lamp and a gearbox arranged to be direct-coupled to the shaft of the machine to be examined, and provided with contacts for making and breaking the lamp circuit. The lamp is arranged as a hand lamp with reflector, and is provided with a long length of flexible wire so as to enable it to be brought to any part of the machine under examination. The current for the lamp is supplied by a 4-volt accumulator through an induction coil, and the making and breaking of the current takes place in the primary circuit of the coil. The induction coil and the accumulator are fixed in the instrument case, the portable form of which is shown in Fig. 27, and do not require to be moved. The gearbox, Fig. 28, is totally enclosed and is arranged for fixing to the end of the shaft of the machine under examination and on the face of the gearbox is a small switch with positions marked "Stationary," "Off," and "Creeping." When in the position "Stationary" the cam which completes the lamp circuit makes contact once in each revolution and, if the gearbox has been correctly attached, the part under examination will then appear in a stationary position. Any point of the cycle of operation of the machine may be viewed by turning the gearbox as a whole as far as required, the gearbox being held by a friction band which can be slacked off for this purpose. By operating levers on the face of the gearbox one, two or four flashes per revolution are arranged for. This provision is of value for the study of vibrations and by its means also the dynamic balancing of high speed machines can be carried out. When the switch on the gearbox is set to the "Creeping" position the machine being examined is seen as though rotating at one hundredth of its actual speed. The makers of the oscilloscope also make an apparatus for driving the gearbox by means of a separate motor which drives a secondary shaft through a variable speed friction drive by means of which a speed variation from 500 r.p.m. to over 3,000 r.p.m. can be obtained on the secondary shaft with constant motor speed. Attachments are provided for mounting the

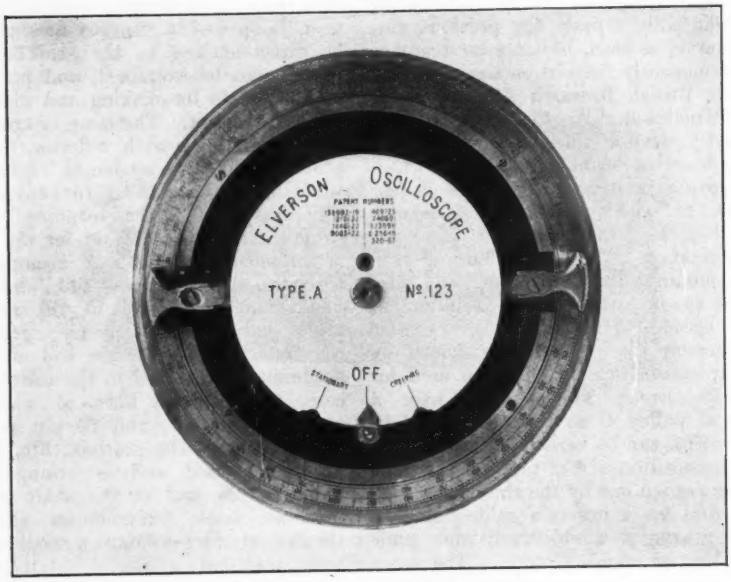


Fig. 28. Gearbox of Oscilloscope.

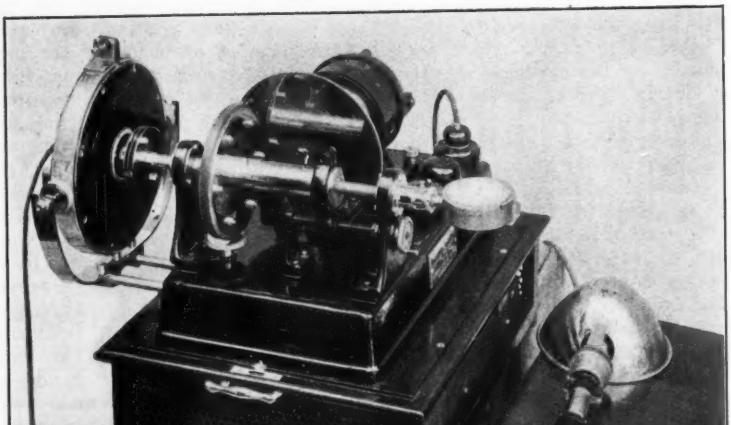


Fig. 29. Synchronising plant for Oscilloscope.

gearbox and contact makers of the oscilloscope on one end of the secondary shaft, on the other end of which a tachometer is mounted. The arrangement will best be seen from the illustration Fig. 29, which shows also the small hand wheel for varying the speed, the motor resistances in the base and other details.

PRACTICAL APPLICATIONS.

The earliest application of the stroboscope was in the domain of physics and for some time its application was limited to this science. It was employed principally for the study of motion. If the speed of a body in motion exceeds a certain value, it is not possible to follow its movements with the unaided eye, since the image of the body in one position persists when the body is actually in another position, and a blur results. This is a very serious drawback to the investigator or to the designer who cannot always foretell the behaviour of bodies in motion from rest conditions. The difference between a body which is in static but not in dynamic balance and one which is both in static and dynamic balance will occur to the mind. Faraday employed the stroboscope to apparently slow down or bring to rest revolving wheels, and Boys and others applied it to the study of jets of water. Parsons used it for the study of cavitation effects with propellers, and succeeded with its aid in effecting improvements in propeller design which made the employment of a steam turbine in direct connection with the propeller a practical possibility.

Another application of the stroboscope was to the study of the electric arc and considerable research has been carried out in this direction.

Perhaps the earliest application of the stroboscope in engineering was to the measurement of the speed of machinery. For this purpose a disc such as that used by Drysdale and illustrated in Fig. 13, or the Robertson disc illustrated in Fig. 14, is mounted on the shaft the speed of which is to be measured, and is either illuminated by flashes of light of known frequency or viewed by glimpses through slits in a tuning fork or a rotating disc. If an equilateral N sided figure is printed on the disc, or equally if there are N radial lines on the disc, the pattern will appear stationary when the speed is $\frac{M}{N}$ revolutions per glimpse, M being any whole number. If the speed is $\frac{M}{2N}$ where M is any odd number, two superimposed images will be seen of the figure. A square, for instance, will appear as an eight-pointed star, or N radial lines will be seen as 2N radial lines. In the same way if the speed is $\frac{M}{3N}$ where M is any whole number not divisible by 3, three superimposed images will be seen on the figure. Measurements of speeds can be made with three and sometimes with four superimposed images, but when a larger number are present the resulting effect is that of a blur, and measurements are not easily made.

From the above it will be seen that by using any one figure on the disc a large number of speeds can be observed, while by the use of figures of different shapes on the same disc speeds in as finely graded steps as may be desired can be determined with a constant glimpse frequency. It is not possible, however, to determine the value of M from observations with one figure, but it can usually be determined by other considerations or by noting the appearance of other geometrical figures on the same disc, there being in general only one speed at which two given patterns will show stationary images. This method of accurately measuring speed has been used extensively for taking running down tests of motors with a view to determining their losses at various speeds, and also for measuring the slip of induction motors, for measurements of phase difference, and for calibrating tachometers. It has also been suggested for the calibration of electricity meters.

Stroboscopic instruments have found considerable application in industry during recent years. A list of over 100 different industries could be made in which such instruments are in regular use. We may take as an example the application to colour printing. In this process the material, whether wallpaper or

Fig. 30. Photograph of cutter revolving at 125 r.p.m., and cam revolving at 250 r.p.m., taken by light of Oscilloscope lamp. Exposure, three minutes.

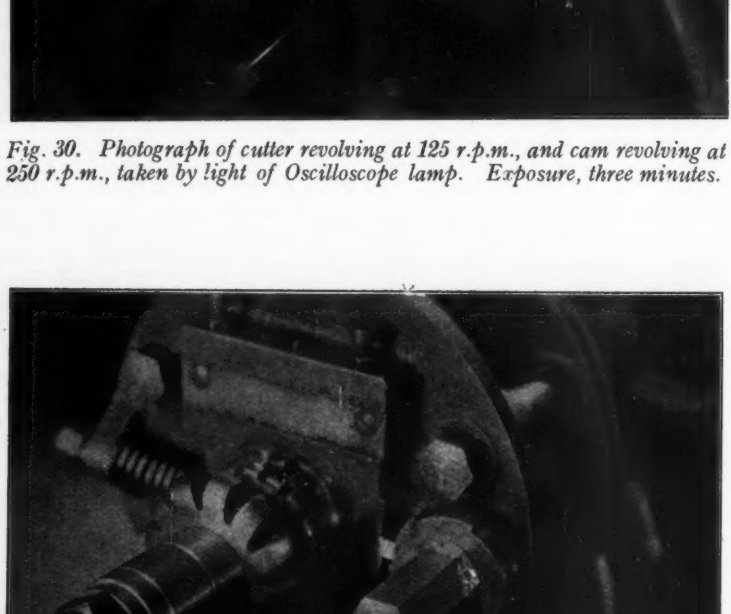


Fig. 31. The same cutter photographed by daylight when stationary.

calico, is generally passed through a series of pairs of rollers, one colour being printed by each pair of rollers. The rollers for each colour must be set so that the colours of the pattern as printed shall register correctly, and in the ordinary course the setting of the rollers must be done at a speed sufficiently low for the pattern to be distinctly visible. When the speed of printing is increased the registration of the colours of the pattern, owing to stretch in the material and other causes, is no longer correct, and it is necessary to slow down in order to correct the setting. The machines must be slowed down in this way frequently during the operation of printing a roll of material in order to secure that the setting remains correct, and that a whole roll is not destroyed through defective registration. By the use of the stroboscope the pattern may be viewed as stationary or as moving very slowly during the whole operation, and adjustment and registration can be made without slowing down. Further, it is possible to increase the speed of working to a very great extent as the difficulties introduced by the stretch of material, etc., can be immediately corrected. This application of the stroboscope shows both the advantages and the limitations of this method. A small patterned cloth repeating itself say 30 times on the periphery of a roller, can be seen as though stationary, and flickering is not noticeable. When, however, a larger pattern with, say, 16 repeats is being printed, flickering becomes apparent, and as more or less continuous observation of the pattern is necessary this flickering is very much more objectionable than it would be in the case where occasional observation only is needed. When an eight repeat pattern or less is being printed lack of persistence of the image is such as to greatly interfere with the utility of the stroboscope if this is arranged to give only one flash for each passage of the pattern. It is possible by the introduction of certain marks on the pattern which repeat at greater frequency than that of the pattern as a whole, for the registration of the colours to be checked on a low repeat pattern whilst still retaining a high flash frequency and avoiding flicker. The registration marks will stand out clearly with the high flash frequency, although the pattern as a whole appears blurred. This method of overcoming the difficulty has, however, the disadvantage that "doctor streaks" and similar defects which are easily observed by the aid of the stroboscope when the whole pattern can be seen, are no longer visible when the registration marks only are discernible.*

The study of out-of-balance conditions of moving bodies and of vibration which generally results from out-of-balance conditions furnishes another field for the use of stroboscopic apparatus. For investigations of this type, it is practically essential that the stroboscopic device should be driven directly from the shaft of the machine under observation. The oscilloscope with its direct driven gearbox is specially suitable for this purpose. As already mentioned, the gearbox of this instrument is provided with a switch by means of which the body under observation can be made to appear in a "stationary" or in a "creeping" or slow moving position. It is further possible, while the switch is in the stationary position, to observe any particular phase of the cycle of operations by turning the gearbox round in the loose sleeve in which it is fitted. By this means the motion of a cam and follower, for instance, can be observed, and any departure from the theoretical curve due to inertia or other causes can be determined.

The oscilloscope gearbox has the further advantage that in addition to giving one image of the driving shaft, two or four images may be obtained in either the "creeping" or the "stationary" position. To take a practical example, if we are observing a vibration which is occurring at shaft speed, we can, if the switch is in the "stationary" position, arrange to view the vibrating body in two positions in its cycle 180° apart, and the distance between the two images as observed will depend on the particular part of the cycle at which

* The author understands that recent improvements have overcome most of the difficulties in connection with this application of the stroboscope.

the observation is made. If, on the other hand, the switch is in the "creeping" position, the two images will appear to periodically approach and recede from each other. By moving the gearbox round so as to get simultaneous views 180° apart of the vibrating body in different positions in its cycle, we can obtain the maximum amplitude of the vibration. The next stage in the analysis is to obtain the principal direction of the vibration. This can be done by putting a mark on the vibrating body and observing the motion of the mark. The two images with the switch in the "creeping" position will take the form of an ellipse, the longest axis of which will be the principal direction of the vibration. The frequency of the vibration can be easily determined, in most cases, from the speed of the driven machine and the number of flashes per revolution required to give the "double-image" phenomenon.

Fig. 23 shows the "double-image" appearance of a gear case subjected to considerable vibration. The magnitude of the horizontal component of the vibration is shown as x and of its vertical component as y. With a view to determining the amplitude and principal directions of the vibration, a punch mark, which appears double in the illustration, has been made on the bearing boss, and on the right hand side is shown the elliptical form taken by the punch mark with the switch in the "creeping" position together with the angle the major axis makes with the horizontal. The amplitude of the vibration where this is small can be measured by means of a microscope and graticule. With a knowledge of the amplitude of the vibration, its direction of greatest amplitude, and its periodicity, together with the speed of the machine, and of other machines in the neighbourhood, there should be no difficulty in locating the cause of the vibration. By an application of the method of analysing vibrations just described an attempt, attended with a considerable degree of success, has been made to balance rotors in their natural bearings. The direction of greatest amplitude is usually first obtained, and if, for instance, this is horizontal a vertical line is marked on the bearing boss. A series of numbered equally-spaced radial marks are made on the periphery of the rotor, a stationary mark being provided so as to enable the position of the radial marks to be located at any moment. The "double image" phenomenon having first been employed to obtain the greatest amplitude of vibration in the plane of measurement, the position of the rotor in this plane is determined by using one flash per revolution and referring to the numbered radial marks, and the direction of movement of the unbalanced mass at the moment of observation is obtained at the same time.

The effect of the time lag in the response of the vibrating masses due to damping is eliminated by taking observations with the rotor revolving in opposite directions and taking the mean of the two observed rotor positions. This method of dynamic balancing can be developed and should be of great value, particularly in cases where either the nature of the periphery of the rotor or its inaccessibility make the ordinary method of marking with a pencil inapplicable.

The Textile industry is one in which the employment of stroboscopic apparatus should be of particular value, and to illustrate this some remarks may be made about its employment in connection with ring spinning frames.

A very large amount of experimental work has been done in various directions with a view to increasing the average speed of the spindle without excessive breakage of yarn, and increasing the permissible maximum counts that can be spun on a ring-frame. With a view to avoiding variations in tension of the yarn owing to the fluctuations in speed of line shafting, individual electrical drive has been introduced, and in addition various variable speed electrical and mechanical individual drives have been employed to automatically regulate the spindle speed according to the position of the yarn on the cop. Amongst the other experiments which have been carried out with a view to increasing the scope of the ring spinning frame may be mentioned the employment of an individual drive for each spindle. To quote some remarks I made some time ago on this subject: "Owing to

well-known peculiarities with a ring frame driven at constant speed, the yarn is subjected to varying tension, and as the speed at which the frame can be run is determined by the maximum tension the yarn will stand, the speed must be such as to prevent this tension being exceeded at any moment, and consequently, with a constant speed drive considerable loss in production occurs. This trouble is well recognised, and numerous attempts have been made to meet it by mechanical means. The majority of these consist in the employment of two separate devices enabling a low speed to be provided for the forming of the base of a cop, when that formation is used, and a higher speed when the base is formed. This does not, however, by any means meet the case, and the only theoretically satisfactory solution so far has been the employment of an electrical drive, which gives not only a low speed during the forming of the base, but also an automatic variation in the speed during the cyclic movement of the ring rail."

The advantage of being able to observe the shape of the "balloon" in the case of ring spinning has long been known, and a series of instantaneous photographs were taken in 1908 by Messrs. Brown Boveri, on which the calculations of the correct speed of spindle for each position of the "build" were based, but the employment of a stroboscope as a means of studying the behaviour of yarn by viewing the "balloon" in its formation directly as though stationary, is more readily carried out, and the results are more immediately available and more convincing than any series of photographs could be. Not only should a stroboscope be of advantage for experimental work in the mill for the observation of the effects of fine adjustments, but it should be of value also in ordinary industrial mill practice for the maintenance of maximum efficiency and to the textile machinist in the design of various machines. The stroboscope employed would be required to give flashes synchronising at will either with the spindle speed or with the speed of the "balloon," or of any other part requiring examination. In order that speed variations of an undesirable kind might be detected, it would be necessary for the stroboscope to be driven independently of the spinning frame drive, and a separately driven stroboscope the speed of flashing of which could be varied readily as required, would probably be the most suitable type to employ.

Conclusion.

Sufficient has probably been said to indicate the importance of stroboscopic apparatus to the Scientist, to the Engineer and to the Industrialist. The significant part about recent developments has been the evolution of robust portable workshop types of instrument to replace the laboratory apparatus which required to be specially fitted up for every experiment and which alone existed a few years ago. This new development, as has been indicated, is based on the discovery of the neon lamp and has led to a widely extended application of stroboscopic apparatus in industry.

The object of this paper is to draw attention to these applications, and to indicate some of the principles on which they are based. If it leads to a greater employment of what the author has always considered a valuable aid to research, it will have served its purpose.

The author desires to acknowledge his indebtedness to Mr. H. M. Lyons for considerable assistance in the preparation of the text, to Mr. R. H. Friend for assistance in the preparation of the drawings, to Messrs. Adam Hilger and to Messrs. Tinsley for the illustrations of apparatus of their manufacture, and to Messrs. H. S. Kennedy for illustrations of the oscilloscope and its applications.

PERSONAL.

Mr. Haydn T. Harrison informs us that in order to obtain increased accommodation he has transferred his office to 14, Victoria Street, Westminster, to which address all communications should be sent in future. He has also asked us to mention that he will be pleased to receive all new issues of catalogues, etc., especially those relating to lighting, which may not have been previously sent to him.

A NEW APPARATUS FOR DETERMINING MEAN SPHERICAL CANDLEPOWER.

THE most widely-known method of determining mean spherical candlepower by a single measurement is by means of the integrating sphere, which is, however, somewhat expensive to construct. Various devices using a series of mirrors arranged at suitable angular intervals round the source and concentrating their light on a stationary photometer have also been used. One drawback, however, is that somewhat large mirrors are needed if extensive light-units are tested.

A modification recently described by J. Sahulka* consists in the substitution of white matt surfaces for the mirrors. These surfaces are placed at selected intervals, such that the aggregate of the light diffusely reflected from each is proportional to the mean spherical candlepower. The objection to mirrors is overcome and the surfaces do not need to be unduly large. But care must be exercised to ensure that the photometric screen is not shadowed by the case in such a way as to cut off a portion of the light from one or more of the surfaces. The arrangement is said to work well. One would imagine, however, that the illumination of the photometer screen might not be sufficient in the case of sources of low candlepower. For the white surfaces plates of plaster of paris may be used, but as these are liable to crack strips of good matt white paper are preferred. The apparatus is calibrated in the usual way by inserting in turn a lamp of known mean spherical candlepower and the source to be tested.

* *Elektrotechnik und Maschinenbau*, Sept. 9th, 1923.

More recently this device has been altered by substituting a continuous strip of paper. This can be in the form of a rectangle. The two vertical sides may consist of strips of uniform width, since the necessary correction for the zones being of different area is automatically made by the fact that the illumination at any point on the vertical strip is proportional to $\cos \theta$, where θ is the angle of incidence. In the case of the horizontal strips of the rectangle, respectively above and below the source, it is necessary to make a special correction for the zone variation. This is done by varying the width of the strip from zero at its centre to a maximum at each corner of the rectangle. Calibration is effected in the same manner as before.

TESTS OF SKY-BRIGHTNESS AND DAYLIGHT ILLUMINATION.

A VERY comprehensive series of tests, made by the committee on sky-brightness, is summarised in the Transactions of the American Illuminating Engineering Society for July. The total (solar *plus* sky) maximum illumination recorded was about 11,000 foot-candles. Some interesting conclusions regarding the comparative effects of clear and cloudy skies are drawn; with a cloudy sky the illumination on a horizontal surface is usually considerably more than twice that on a vertical one, owing to the fact that the region of maximum sky-brightness is near the zenith. At Chicago, where the atmosphere is smoky, the illumination from a cloudless sky was in general only about two-thirds that on a similar surface at Washington, where the atmosphere is relatively free from smoke.

SOME NOTES ON THE NATIONAL GAS EXHIBITION.

(Held in Birmingham, September 17th—October 3rd.)

BY AN ENGINEERING CORRESPONDENT.

THE National Gas Exhibition, opened at the Bingley Hall, Birmingham, on September 17th, was held at an opportune moment. It is quite a number of years since a gas exhibition of any magnitude was last held, and Birmingham appears to be a very appropriate locality, in view of its early association with the production and use of gas. The Exhibition contained an historical section and it is stated that Birmingham furnished about half of these exhibits. It is well known that at one time Mr. Joseph Chamberlain was Chairman of the Corporation Gas Committee and one of his pocket books, containing methodical records of his work in this connection, was on view. By a very convenient arrangement the Annual Meeting of the British Commercial Gas Association was this year held at the Exhibition, and a number of interesting addresses were delivered. There were also popular lectures and demonstrations, which formed a useful supplement to the display of modern apparatus.

Several of the lectures dealt with smoke-abatement. On the opening day Dr. R. H. Jolly, Medical Officer of Health for Wolverhampton, lectured on "Smoke and Ill-health," while Miss Nora March dealt with the same subject in relation to infant mortality. Dr. C. W. Saleeby, in connection with the B.C.G.A. gathering, alluded to the same subject in his lecture on "Light and Life." Slides were exhibited to show the valuable results achieved in America, Switzerland, Denmark and England by the aid of sunlight in the curation of tuberculosis. There were, he remarked, many diseases which could be eliminated by the application of sunlight. The pervasion of the air by smoke, and the consequent absorption of the light of the sun, was one of the great defects from which large cities in this country still suffered.

THE ROMANCE OF ARTIFICIAL LIGHTING.

A well illustrated lecture on "The Romance of Artificial Lighting" was delivered by Capt. W. J. Liberty, who has been for over 44 years in the Public Lighting Department of the City of London, and has made a special study of the historical side of illumination. The lecturer illustrated some of the most primitive lighting devices, and recalled the early days of street lighting in London, when there was an obligation on all householders to hang out lanterns. It was only gradually that the duty of street lighting passed into public hands, and at first oil lamps and later gas lamps were installed by them.

The introduction of gas lighting more than 100 years ago was destined not only to alter radically the habits of people, but to increase very greatly their earning capacity. Yet, as was so often the case with new inventions, the new development was at first opposed by the workers. When Westminster Bridge was lighted by gas in 1813, Clegg, the great engineer, was at first obliged to light the lamps himself, as he could not obtain labour. The Guildhall was lighted two years later, on the occasion of the Lord Mayor's Banquet. The charging for gas by meter, instead of "per burner" was an important step, but it was the coming of the incandescent mantle that really revolutionised gas lighting. In this connection Capt. Liberty recalled the visit of a representative of Auer von Welsbach, the inventor, who asked to be allowed to put up a "stocking" in the Guildhall, as a demonstration. But the day after it was fixed he found a little heap of ash on his blotting pad; this was the end of the first Welsbach mantle he had knowledge of in the City of London!

In the later section of his lecture, Capt. Liberty alluded to the coming

of the inverted mantle, and other advances, and especially the important development of street lighting. In the 500 miles of streets in the Metropolis there were now about 30,000 lamps (gas and electric) under the control of the City of London Corporation, the L.C.C., and the 28 Borough Councils.

Importance of Research Laboratories.

Other lectures dealt with the by-products derived from the distillation of coal and their uses; gas service as an aid to the housewife, gas for catering, and the application of gas in various specific industries. Special interest attaches to the account given by Mr. A. W. Smith of the experience of the Birmingham Corporation Gas Department in developing a suite of laboratories where manufacturers can have any tests of a chemical, metallurgical or engineering nature carried out. These laboratories, which are under the supervision of Dr. C. N. Walter, formerly associated with Birmingham University, form a most useful supplement to the industrial showrooms. Every gas undertaking cannot equip laboratories and employ a staff on this scale, but the B.C.G.A. proves a channel through which information thus acquired can be made available to smaller concerns.

The B.C.G.A. Conference.

Many of the above addresses were delivered in connection with the B.C.G.A. Conference, and there was also much of interest in the addresses delivered at the Business Meeting. The Lord Mayor of Birmingham, in welcoming the Conference, emphasises the important opportunities of witnessing progress provided by the Exhibition, and the facilities for exchange of views of representatives of gas undertakings. He recalled that the total output of gas in Birmingham was now nearly six times what it was when the Corporation took over the business in 1875. A letter from Sir W. Joynson-Hicks (Minister of Health) expressing regret at inability to attend and good wishes for the success of the Conference was read. The President (Alderman J. H. Lloyd) mentioned that his own connection with the Birmingham Gas Committee dated back to over 32 years ago, and he recalled the days of Mr. Chamberlain and the work of Mr. Chas. Hunt, who was engineer to one of the companies taken over in 1875. He also expressed his appreciation of the valuable work of the B.C.G.A., in emphasising the services of gas to humanity. The Association was now constantly being asked to provide information on the uses of gas and a good instance of its propaganda work was furnished by the *Teacher's Notes* widely circulated in the schools by many gas undertakings.

The Rt. Hon. J. R. Clynes, M.P. (President of the National Confederation of General Workers), dealt more especially with the human factor, and remarked on the good relations in general existing between employers and workers in the gas industry. The National Joint Industrial Council has improved the spirit of co-operation. The gas industry was subject to seasonal changes and new methods of production, which introduced complexities. Employers must endeavour to secure the confidence of their workpeople, but no system of under-production could be tolerated. Real wealth could only be expressed in terms of work.

After a vote of thanks to Mr. Clynes had been passed with acclamation, Mr. F. W. Goodenough (Executive Chairman) presented a record of the continually increasing activities of the Association. At the same time the Executive recognised that much remained to be accomplished, especially in devising a good scheme of education for the commercial side of the industry. The industry was represented to the public by its outdoor representatives and up to now insufficient had been done to educate and train the sales staff. Further appreciation of the work of the Association was expressed at the luncheon and dinner on October 2nd.

The Exhibits.

While it is only possible to mention a few main features of the exhibits concerned with lighting, reference should first be made to two stands of a general character, those of the B.C.G.A. and

the Birmingham Gas Department. The former included a special exhibit dealing with smoke-abatement and a stall devoted to literature of all kinds, illustrations of methods of propaganda, etc. There were also model gas showroom windows and examples of showcards, office equipment, etc. The display of the City of Birmingham Gas Department, besides containing examples of the latest devices for lighting, heating and industrial uses, included a model canteen, a working laundry and a demonstration by the Gasfitters' Assistants' Training School. An exhibit of special interest was that designed to show the effect of coloured papers on illumination, a series of eight miniature rooms, each with walls of a different colour, but all containing an incandescent burner of identical candlepower, being arranged.

Generally speaking, the exhibits emphasised the conclusion arrived at in a recent contribution by Mr. N. H. Humphreys to the *Gas Journal*, that lighting by gas is by no means a field to be neglected. Appealing as it does directly to the eye, effective lighting is one of the best of advertisements. It is also remarked that high-class street lighting by gas is usually accompanied by a large consumption per head of population.

A feature was the number of good examples of semi-indirect lighting. The "Carlton" fitting shown by H. T. Staniforth & Co. is an instance of the simple open bowl type while the "Gayton" form shown by the same firm, utilises an upper-reflector forming a false "ceiling" for purposes of reflection. The "Rodney" fitting is a compact lighting unit with diffusing bowl. Messrs. Falk & Stadelmann besides illustrating the development of the mantle in all its stages showed the "super-Veritas" and "Quick-Grip" burners, the latter being a single burner readily applied to semi-indirect fittings of a pleasing type.

The New Inverted Incandescent Lamp Co., Ltd., Messrs. J. & W. B. Smith, Ltd., and other firms also included semi-indirect fittings in their exhibits. A feature of Messrs. Wm. Sugg & Co.'s stand was the variety of "Elite" and burners in polished aluminium, the "Exeter" specially designed to replace uprights in churches, etc., the Windsor street lamp, various "conversion" fittings, and of course the distant control devices with which this firm is associated. There were also several examples of gas illuminated signs, notably the "flashometer" shown by Thos. Glover & Co. which enables six different messages to be conveyed in different directions, and the Walker automatic signs, with which lighting effects controlled at various flashing intervals are possible.

The Thermal Syndicate showed a wide range of "Vitreosil" glassware. It is worth noting that, apart from the primary advantages of robustness, good heat-resisting power and diffusion of light associated with this material, pleasing variations in colour can now be obtained; the material, on account of its comparative lightness, also finds ready application in the form of semi-indirect bowls.

The exhibit of the Welsbach Light Company was naturally devoted mainly to mantles. The demonstration of the method of manufacture, from the knitting of the stocking from Ramie silk yarn to the drying, packing and distribution of the finished mantle, was probably one of the most complete ever given publicly. Naturally it was necessary to select those processes which lend themselves best to display, and it must not be overlooked that there are in all as many as 22 operations to which mantles must be subjected in the factory. There was also a representative collection of Welsbach-Kern radiators, burners, pendants, brackets, etc., as supplied by this Company.

The historical section contained many early documents and letters illustrating interesting phases of the early development of gas lighting contributed by the Birmingham Gas Department. Messrs. Walter King & Co., Ltd., exhibited some interesting early books and tracts and Messrs. Wm. Sugg & Co., Ltd., had on view a series of burners illustrating progress up to the incandescent mantle.

GOOD LIGHTING AS AN AID TO SAFETY.

A NEW and revised version of the illustrated booklet under the above title, by Mr. Leon Gaster, has now been issued by the British Industrial "Safety First" Association. The introductory section contains arguments in simple language explaining the benefits of good illumination in the interests of health, safety and efficiency. A chart illustrating the greater frequency of industrial accidents during the dark winter months, when artificial light is mainly used, is reproduced and some sketches are included showing how various accidents may be caused by inadequate lighting. It is pointed out that the cost of good lighting in general only forms less than one per cent. of the cost of production. Reference is also made, in two new sections, to the importance of good lighting in mines and on railways.

The fundamental principles of proper lighting are explained and illustrated by numerous diagrams and photographs including some views of the large repair shops of the London General Omnibus Co. at Chiswick. The chief recommendations contained in the reports of the Home Office Departmental Committee on Lighting in Factories and Workshops are summarised and the schedule dividing industrial operations into "fine" (requiring not less than three foot-candles) and "very fine" (requiring not less than five foot-candles) is reproduced as an appendix. It is pointed out that these values are intended as an indication of minimum values recommended in practice, but not as a basis for legal minima.

ELECTRIC LAMPS IN LIGHTHOUSE SERVICE.

AN article by L. C. Porter in the *General Electric Review* points out that electric lamps are now coming into use for navigation coast-lights, etc. Difficulties have now been very largely removed by the design of suitable lamps and batteries for places where electric supply is not available. A special flasher has been developed, and apparatus can also be supplied with an automatic solar valve, similar to that used with acetylene. With typical outfits a beam candlepower of 50 can be obtained. An electric outfit only costs about 18 dollars per year for batteries and one dollar for lamps, and the cost of installation is stated to compare favourably with that of other systems.

THE LIGHTING OF A SILK-WEAVING FACTORY.

THE lighting of looms in a silk-weaving factory is a somewhat difficult problem. Hitherto local lights have usually been thought necessary, as overhead illumination is apt to cast troublesome shadows. But local lighting has drawbacks. Lamps are liable to get broken and replacement by unsuitable shapes may lead to glare. Also with opaque reflectors there is disagreeable contrast between the bright local illumination and the darkness in the upper part of the room.

Mr. H. W. Desaix, in the *Transactions of the American Illuminating Engineering Society* for September, 1923, summarises some experiments designed to ascertain the best mode of lighting. Tests were made in a room containing 24 plain broad looms, arranged six in a row. As a result of conferences with mill executives, foremen and operators, it was agreed that the desired system should give adequate illumination, higher on looms than in aisles, freedom from objectionable shadows and glare, and sufficient light on the walls and upper parts of room to eliminate undue contrast. Costs of upkeep and maintenance must also be reasonable. The lighting unit decided upon consisted of a rugged prismatic glass reflector, open top and bottom, and with adjustment for 75, 100 and 200-watt gasfilled lamps. The units were spaced on centres over each loom station or weavers' alley, *i.e.*, 13 ft. 3 in. between units along rows and 10 ft. between rows on each side of centre aisle. The mounting height was 12 ft. above floor and about 9 ft. above working plane, which was sufficient to guard against likelihood of breakage. With 200-watt lamps there was an illumination of 30 foot-candles on the tapering to 15 foot-candles in the aisles.

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TOPICAL AND INDUSTRIAL SECTION.

[At the request of many of our readers we have extended the space devoted to this Section, and are open to receive for publication particulars of interesting installations, new developments in lamps, fixtures, and all kinds of apparatus connected with illumination.

The contents of these pages, in which is included information supplied by the makers, will, it is hoped, serve as a guide to recent commercial developments, and we welcome the receipt of all *bona-fide* information relating thereto.]

ILLUMINATING GLASSWARE.

Two catalogues being issued by Messrs. Siemens and English Electric Lamp Company, Limited, deal respectively with Holophane and "Moonstone" illuminating glassware.

The Holophane list contains an up-to-date selection of stiletto reflectors, reflector-refractors, excellite and reflector-bowls, etc., a feature being the data assembled, giving particulars of polar curves and resultant illumination with various sizes of lamps and heights of suspension. There are also several pleasing illustrations, showing actual results in lighting residences, shops, etc.

The Moonstone glassware, of moulded diffusing glass, is also available in the form both of bowls and reflectors, some of a highly ornamental character, well adapted to semi-indirect lighting. One would, however, like to see the illustrations accompanied by polar curves and engineering data, similar to that included in the other catalogue.

WELSBACH SPECIALITIES.

THE Welsbach General Catalogue for the season 1923-24 is of imposing dimensions. Naturally attention is devoted primarily to mantles, which are listed in great detail, and it is pointed out that prices have been considerably reduced. Next we find the "Economy" upright and inverted burners, and various forms of superheater and cluster burners illustrated. There is a wide range of fittings of all kinds, amongst which attention may be directed specially to "Supastone" diffusing bowls, suitable for semi-indirect lighting, which promises to become as popular with gas as with electric lighting.

It is interesting to recall that the Welsbach Light Company does not confine itself to gas. Electric lighting fittings and incandescent oil lamps are also listed, and one likewise finds particulars both of gas and electric heating appliances.

THE LIGHTING OF THE TIVOLI CINEMA.

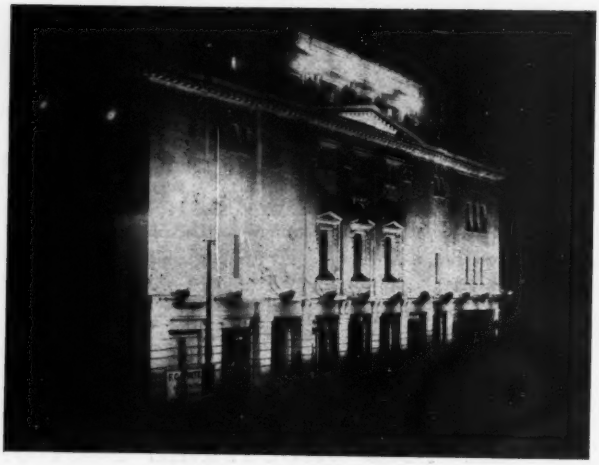
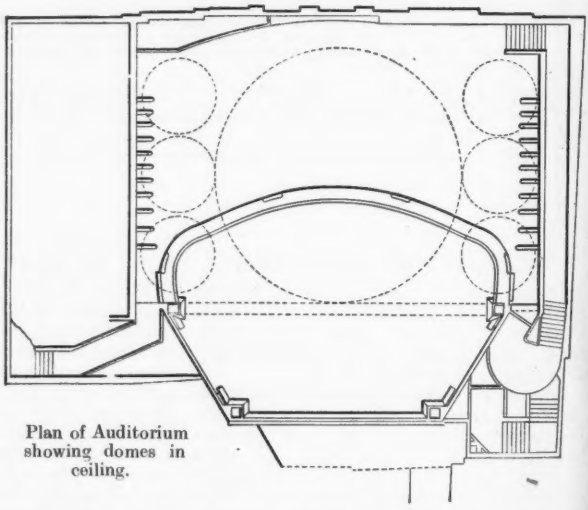


FIG. 1.—Showing effect of external floodlighting at night.

AN account which we have received of the lighting of the new Tivoli Cinema in the Strand, the scheme for which was designed by the Illuminating Engineering Dept. of the General Electric Co., Ltd., in conjunction with the architect, Mr. Bertie Crew, presents interesting features.

First, as regards external lighting. The frontage facing the Strand is floodlighted by 24 units, 12 equipped with 500-watt lamps and 12 with 200-watt lamps. These are mounted on ornamental bronze brackets and concealed by bronze screens, and the night view (Fig. 1) gives a good idea of the effect produced.



Plan of Auditorium showing domes in ceiling.

Second, in regard to interior lighting. The novelty lies in the fact that practically all the lamps are concealed. In the auditorium there are no projecting fittings. The main illumination is derived from the main dome, 54 ft. in diameter and six subsidiary domes, each 16 ft. in diameter. Lamps are hidden in a moulded cornice round the circumference of each dome, and are arranged in three circuits, yielding respectively amber, blue and rose coloured light. Each circuit is controlled by a dimmer and a great variety of colour-effects can be secured. Under the gallery and balcony the lighting is supplemented by ceiling panels of special design, designed to furnish varied colour-effects similar to those achieved with the main lighting. There are also amber panels in the walls furnishing supplementary lighting, whilst projectors using colour-sprayed Osram lamps are sunk flush in the gallery to illuminate the proscenium arch.